

# ***SUMMARY OF RESEARCH 1995***

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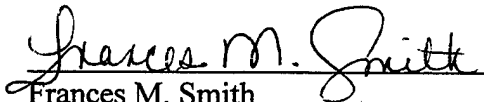
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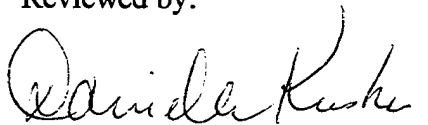
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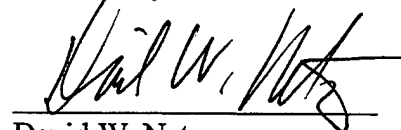
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This report contains 35 summaries of research projects in the Department of Mechanical Engineering which were carried out under funding of the Naval Postgraduate School Research Program. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, and technical reports.

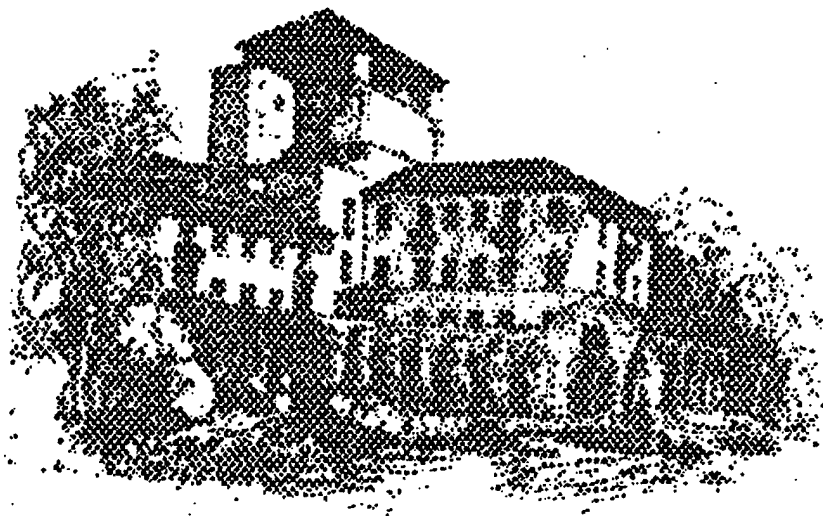
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## **THE NAVAL POSTGRADUATE SCHOOL MISSION**

The mission of the Naval Postgraduate School is to provide advanced professional studies at the graduate level for military officers and defense officials from all services and other nations. The School's focus is to increase the combat effectiveness of the armed forces of the United States by providing quality education which supports the unique needs of the defense establishment.



## Introduction

Research is an integral part of graduate education. At the Naval Postgraduate School (NPS), the goals of research are to:

- Provide a meaningful, high quality, capstone learning experience for our students.
- Keep faculty on the leading edge of advances in defense-related science, technology, management and policy to ensure that the latest information is incorporated into NPS courses and curricula.
- Apply faculty and student knowledge to enhance Navy/DoD operational effectiveness.

Pursuit of these goals increases the technical and managerial capability of the officer corps to keep pace with an increasingly complex defense posture in today's world.

The overall research program at NPS has two funded components:

- The Direct Funded Research (DFR) Program provides internal funding from the School's operating budget to stimulate innovative research ideas of benefit to the DoN and may be used for cost-sharing with reimbursable research efforts. This funding ensures, in particular, that all Navy-sponsored NPS curricula are equitably supported, that new faculty are provided an opportunity to establish a research program of importance to DoN/DoD and other national security interests, and that faculty and students from across the campus are encouraged to interact with one another.
- The Reimbursable Research (RR) Program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policy makers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. This ensures that NPS research remains highly regarded by academic peers and government officials and fosters a closer relationship between NPS and other outside organizations.

The two research programs are complementary and ensure that the overall research program is flexible, responsive, balanced and supportive of the unique needs of the military.

All research projects, both reimbursable and direct funded, support the School's research mission:

- To develop an overall research investment strategy that ensures a high quality, creative learning experience for NPS graduate students.
- To encourage faculty and student pursuit of new discoveries and applications which enhance the long term effectiveness of the armed forces.
- To stimulate interactions between NPS faculty and a wide variety of potential research sponsors (Government, Universities, Private Industry).
- To publicize (both internally and externally) significant achievements of the NPS research program and market NPS research capabilities.
- To foster synergy and force multiplication with Navy/DoD commands and laboratories to increase the potential for successful research and development programs

The Department provides a broad based graduate education in the fields of Mechanical Engineering. This imparts the relevant skills necessary for the design, acquisition, maintenance and overhaul of modern warships and Naval systems. The interconnectedness of the fundamental areas of fluid mechanics, thermal sciences, propulsion, controls, structural mechanics, dynamical systems, materials engineering, systems engineering, and design is stressed throughout the program. The uniqueness of the program is achieved by using the focus of the Naval vessel and Navy systems to provide a context for the teaching and demonstration of the required engineering principles. This focus and relevance of the program has provided the high quality which has assured the continuing ABET accreditation of the program.

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The Department of Mechanical Engineering's research program continues to advance the state of knowledge in areas of relevance to the Navy. These areas include: fluid mechanics research on the interaction of turbulent jets with free surfaces; work in thermal sciences involving applications to fire spread in confined spaces; research in solid mechanics, structural dynamics, underwater shock, and fracture of composite structures; study of the control of autonomous underwater vehicles and of the control of flexible structures; and materials research into welding of alloys for naval structures and development of metal matrix composites for military applications. Results of research are published in student theses, NPS technical reports, and in papers presented both at, and appearing in, national conference proceedings, and published in scientific journals. The following is an overview of each area of research with individual faculty summaries.

## Solid Mechanics, Shock and Vibration

### YOUNG S. SHIN, Professor:

Professor Shin has continued his investigation of "Response of Naval Structures to Underwater Explosions" under the sponsorship of the Defense Nuclear Agency (DNA), and Naval Surface Warfare Center (NSWC) - Annapolis Detachment. For the DNA project, the analytical and numerical studies of underwater explosions and their effect to the naval structures have been conducted. There are three basic features; (i) shock wave propagation through the surrounding hydro-acoustic medium and the behavior of explosive-gas bubble, (ii) structural dynamics problems with material and geometric nonlinearities, and (iii) fluid - structure interaction and explosive gas bubble - structure interaction. NSWC-Annapolis has been developing Advanced Lightweight Influence Sweep System (ALISS). ALISS is an Advanced Technology Demonstration to validate the feasibility of superconducting technology to sweep magnetic influence mines in shallow water. Under the extremes of shock and vibration environment, the high magnetic field of the superconducting coil may collapse and jeopardize its mission. Professor Shin developed operational shock and vibration criteria to be designed into ALISS and have been performed numerical simulation of dynamic response of superconductor magnet.

### YOUNG W. KWON, Associate Professor:

Professor Kwon worked on several projects during this reporting period, both are sponsored and unfunded. One project sponsored by the Naval Medical Center on biomechanics studied the human knee injury and evaluated ligament reconstruction techniques. In addition, both experimental and analytical studies were conducted on osteonecrosis (bone disease) of the femoral head. Another project funded by the Naval Surface Warfare Center dealt with numerical modeling techniques of submerged structures exposed to underwater shock. The major goal was to develop a simplified numerical model for submerged stiffened cylinders so that both computational time and manhours could be saved. One unfunded project researched damage and failure modeling of fibrous composite structures. A micro/macro-mechanics concept was developed to predict fiber breakage, matrix cracking, and fiber/matrix interface debonding. The other unfunded project involved failure of sandwich composite structures under impact and/or compressive loads. Emphasis was placed on investigating the effects of existing defects such as cracks and holes on the failure modes. Experimental analysis as well as numerical simulation was undertaken.

### JOSHUA H. GOLDIS, Assistant Professor:

Professor Joshua H. Gordis is conducting research in several areas in structural dynamics and vibration. In structural synthesis, a family of analytic methods have been developed which allow the direct calculation of modified dynamic response of structural dynamic system computer models which have been arbitrarily modified and/or combined with other models. These methods are distinguished by their ability to treat modifications of arbitrary size, distribution and damping, provide a highly efficient and exact solution in all cases.

Research is also being performed in structural system identification, where deficiencies in math models are identified through the use of measured dynamic response data. Recent results here include the identification of a non-standard

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set of eigenvalues which provide a additional, independent data with which to tackle the underdetermined system identification problem. The system identification methods are being applied in the area of structural damage detection, which seeks to uncover structural damage in components using measured dynamic response data. Additional areas of research include the optimization of shipboard topside equipment with respect to weapons effects, the structural dynamic analysis of the Sikorsky RAH-66 Comanche helicopter and vibration testing of the McDonnell-Douglas OH-6 helicopter.

## Ship Systems

CHARLES N. CALVANO, Associate Professor:

During 1995, Professor C. N. Calvano performed research under four funded projects. Sponsored by the Office of Naval Research (ONR), and working together with Professor Fotis Papoulas, Professor Calvano continued to provide design evaluation and oversight of the SLICE ship design being performed for the ONR by the Lockheed Company. This project was a basis for seven Master of Science of Mechanical Engineering theses and concluded successfully when the SLICE ship began construction. Professor Calvano also performed design assessment and evaluation for the U.S. Air Force Electronics Systems Center as part of their project to modify an oceanographic research ship to be used to carry a Sea Based Transportable Radar system.

Reimbursably funded work in support of Navy ship programs, construction of the SC 21 (21st Century Surface Combatant) was done for the Navy Program Office. The task was to ensure the incorporation of the highest quality Total Ship Systems Engineering methods and process in the development of the Systems Engineering Master Plan (SEMP) for this ship development. In support of the Naval Sea Systems Command Systems Engineering and Surface Ship Design Group, Professor Calvano performed research in the development of ship systems analysis and assessment methods. An automated method for determining Measures of Effectiveness (MOEs) for Navy task groups will form the subject of a future publication based on this work.

## Dynamic Systems, Controls and Robotics

ANTHONY J. HEALEY, Professor:

Professor Healey was active in furthering the technology of Autonomous Underwater Vehicles. In particular, the *Center for Autonomous Underwater Vehicle Research* has formally been approved. Its facilities include the AUV laboratory in Building 230 housing a 20 feet by 20 feet, 6 foot deep vehicle systems test tank that will support autonomous hovering maneuvers and high frequency imaging work of the AUV "Phoenix," a testbed vehicle designed and operated by the Center. In late 1995, a major advance was made towards performing the first autonomous mission in open water at the dock facility of the Monterey Bay Aquarium Research Institute. While this mission was not completed in 1995, major software developments were performed including the purchase and networked installation of a SUN Voyager notebook computer in the Phoenix vehicle. The AUV laboratory has been equipped with a radio ethernet connection to the NPS campus backbone and the vehicle computers are now installed as part of that network. This has facilitated rapid code development and file transfer so that student thesis work can be performed either on campus or at the Laboratory.

A major demonstration was performed during the Mine Countermeasures Conference hosted at NPS by a committee including Professor Healey, in which sonar imaging of a cylindrical target was performed in the laboratory test tank but where the initialization of the mission and the display of the sonar images were in the Computer Science Graphics Laboratory. Approximately 50 visitors were present to view the results of the experiment.

International visitors to the Center included Professor Antonio Pascoal and his Ph.D. student, Carlos Silvestri, from the University of Lisbon in Portugal who have worked with Professor Healey in the development of Petri Net methodology for the discrete event control of AUV missions.

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The effort is funded by the National Science Foundation, the Office of Naval Research, and the Naval Explosives Ordnance Disposal Technical Division.

## MORRIS DRIELS, Professor:

Progress has been made on the NASA funded project in various implementation of passive motion resistance due to feedback of external forces from a remote environment. In this scheme, the rotation of a joint is resisted by a brake such that the braking resistance (torque) is proportional to the signal from a force sensor placed in the slave part of the teleoperator. In this way, active actuation, with its accompanied size and weight, is avoided, and a small, lightweight system results.

In FY95 work on the Army funded project focused on implementing the perspective view generator algorithms, initially developed by TRAC contractors, on a single CPU workstation. This was accomplished early in 1995, and gave excellent visualizations of the terrain, with a frame rate of about 1-2 frames/second. Following this, the target acquisition algorithms found in ACQUIRE were implemented, showing how some of the detection parameters could now be calculated in a dynamic, rather than a static manner. Also, work was done to convert the algorithms to run on parallel processing workstations, and lead to an improvement in frame rate to around 9 frames/sec.

## FOTIS A. PAPOULIAS, Associate Professor:

Professor Papoulias conducted research on several aspects of SLICE hulls including resistance, seakeeping, and maneuvering properties. A SLICE hull is a variant of the more familiar small waterplane twin hull (SWATH) with separated fore/aft buoyancy modules. Comparative calculations demonstrated that a SLICE may offer decreased resistance compared to an equivalent size SWATH. Several key parameters and their effects on resistance were identified. Seakeeping studies proved that SLICE hulls have excellent response characteristics. While this is true in all six degrees of freedom and for most speeds, sea states, and directions, the results indicated the inadequacy of current seakeeping prediction methods that are based on strip theory, in predicting realistic values for system damping both in roll and in heave/pitch. In the area of maneuvering, a number of techniques were applied in order to evaluate the hydrodynamic coefficients and turning characteristics of SLICE hulls. Finally, a critical examination of various resistance scaling laws explained the large differences in the predicted values for the full-scale ship resistance that were proposed. It was concluded that the classical Froude's scaling law would severely over-predict the resistance of a SLICE hull. A new method bridges the differences between Froude's and Hughes' techniques, and is believed to be more accurate for such a hull.

## RANJAN MUKHERJEE, Associate Professor:

Professor Mukherjee is principal investigator on two main projects. The first project is aimed at the development of a flexible, surgical, robotic arm to aid in minimally-invasive surgical procedures. Current instrumentation in minimally-invasive surgery is highly constrained with respect to the maneuvers available to the surgeon. This limitation can be overcome through the advancement of current technology and its integration geared towards the development of a controllable, flexible, robotic arm. A novel articulated linkage has been designed to serve the purpose of the robotic arm. This linkage provides the scope for miniaturization and dexterity through articulation, and can apply sufficient forces to perform surgical procedures.

The second project is more theoretical in nature and investigates the repeatability problem in nonholonomic systems. Nonholonomic systems behave in a way that closed trajectories of the independent variables result in a change in the dependent variables. There are certain nonholonomic systems for which closed paths in the space of the independent variables can be designed such that the net change of the dependent variables is zero over these closed paths. Then these trajectories are like "holonomic loops" over which the nonholonomic system exhibits holonomic behavior globally. Such systems are important from a practical standpoint, as in the case of kinematically redundant manipulators under pseudoinverse control, where repeatable trajectories will eliminate the drift under pseudoinverse control. As a part of this project, the investigator is also working on the motion planning and control of nonholonomic mobile robots. The

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motion planning problem is based on the framework of optimal control theory and the control problem is based on the concept of ultimate boundedness.

## Fluid Dynamics, Heat Transfer and Turbomachinery

### TURGET SARPKEYA, Distinguished Professor:

The statistical as well as structural characteristics of the turbulent flow field resulting from the interaction of a swirling turbulent jet with clean and contaminated free surfaces were investigated through the use of LDA, LIF, and CFD in order to elucidate the physics of the phenomena relevant to the understanding of near-surface structures in ship-generated wakes. Second, a critical assessment of the capabilities of computational fluid dynamics has been made through the solution of several massively-unsteady incompressible flows. Third, a detailed mapping of the spatial and temporal variations of conductivity in the wakes of submarine-shaped bodies has been carried out. Finally, a major investigation of turbulent vortex breakdown has been undertaken.

### MATTHEW D. KELLEHER, Professor:

Professor Kelleher has been continuing work on liquid cooling of electronic components and equipment. The most recent work has dealt with the investigation of the heat transfer capabilities and effectiveness of liquid flow through modules for electronics cooling. The investigation used a Standard Electronic Module, format E (SEM-E) size flow through module with a dielectric polyalphaolefin as the liquid coolant. One surface of the module was populated with six etched foil heaters placed over the flow path. Thermocouples attached to the module surface and also placed in the inlet and outlet tubing provided data to quantify module effectiveness and heat transfer characteristics for a variety of power inputs and liquid coolant flow rates. Work has also been conducted to investigate the details of the heat transfer process internal to the flow through module. To carry out this study, a ten times blow up model of the offset plate finned array structure of the internal passages of the flow through module was constructed. Preliminary heat transfer and flow visualization data have been obtained for this model.

Professor Kelleher has also been conducting a study of the boiling characteristics of highly wetting liquids such as the dielectric liquids used in electronics cooling. This work is studying methods to overcome the large superheat temperatures necessary to initiate nucleate boiling which are characteristic of these liquids. Previous work has investigated the use of auxiliary heaters to initiate the nucleation process. It was shown that this method can drastically reduce the required nucleation superheat. The most recent work has investigated the effects of oscillatory flow on the nucleate boiling process. Results have indicated that, in a specific range of frequencies and amplitudes, reduction of the superheat is achieved.

### KNOX T. MILLSAPS, Assistant Professor:

Methods to reduce lateral vibration of gas and steam turbine rotors are being investigated using both analytical and experimental techniques. Using steady state and transient lumped parameter models and an experimental rotor facility, the impact of several parameters on rotordynamics response, including asymmetric bearing parameters, acceleration rates, etc., have been investigated. Design rules for minimizing vibration amplitude have been developed for the steady state cases. Work is on going for extending these results to accelerating rotors. Preliminary results show that it is possible to schedule acceleration, to minimize lateral deflections (either maximum or integrated vibrational energy) as the rotor transits through critical speed. Optimum acceleration schedules are being sought.

Research into predicting the condition of a diesel engine are being developed. Specifically, an engine cycle analyzer is being used to assess induced combustion faults and to localize them. Techniques based on high response instrumentation and advanced signal processing, such as Joint-Time-Frequency-Analysis (JTFA) are being applied to identify patterns characteristic of certain classes of faults. Determining the type of faults that can be detected and

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localized and the specific type of JTFA that is optimum for a given fault is the primary focus of the research. To date fuel injection timing faults of a diesel have been localized using this method. Methods for replacing direct in-cylinder pressure measurements with secondary measurements are being pursued.

## ASHOK GOPINATH, Assistant Professor:

Professor Gopinath has been conducting research in "Convective Heat Transfer Induced By Strong Acoustic Fields." The research objective is to develop correlation for calculating convective heat transfer rates induced by strong acoustic fields around a cylinder. This work was motivated by the need to provide a better understanding of the heat transfer behavior in internal oscillatory flows with application to the improvement of the design of heat exchangers in thermoacoustic engines. An experimental rig was constructed to first explore geometries of fundamental interest, such as a cylinder, which make up one of the basic component shapes in a heat exchanger.

The rig had a cylindrical cartridge heater (with a built-in thermocouple) positioned along the diameter of a cylindrical resonant duct in which a plane resonant standing wave was excited using a high-power compression driver. Power and temperature measurements at steady state provided the necessary data to deduce the heat transfer coefficients. A large amount of data was gathered and should be valuable in future heat exchanger design. A theoretical analysis of the thermoacoustic streaming phenomenon responsible for generating the time-averaged heat transfer effects in a thermoacoustic engine was also conducted. Basic parallel plate geometry in a high-intensity zero-mean oscillatory flow was considered, which provided considerable insight into the effects of gap width, and would be of use in determining the optimum gap width in the stack of a thermoacoustic engine.

## Materials Science

## TERRY R. MCNELLEY, Professor:

Professor McNelley concluded a program of research on processing of cast Al 6061 - Al<sub>2</sub>O<sub>3</sub> metal matrix composites (MMCs) that had been funded by Duralcan-USA, a composites manufacturer located in Detroit, MI. These materials offer many desirable properties but are lacking in ductility and fracture toughness. This work demonstrated the feasibility of ductility enhancement during processing utilizing methods developed at NPS. This has lead to a new program with funding by the Army to apply these methods to enhancing the fracture toughness of such MMCs as well as to understand the mechanisms of microstructural evolution during the processing of such materials. Potential uses of these MMCs include applications such as light armor. In another program, a sensor system has been developed that is capable of monitoring in real time the aging response of age-hardenable materials. This sensor system utilizes eddy current coils, a specially designed amplifier and computer-controlled data acquisition to obtain resistivity data during aging. In conjunction with a controller, such a system will allow more precise regulation of heat treatment processes and, thereby reduce material variability and improve component reliability. Finally, research on processing of superplastic aluminum has continued with the focus of efforts primarily on the role of processing in the development of the grain boundaries types necessary for extensive superplastic response. This work has also examined the role of alloy composition and the importance of second-phase particles in determining the nature of grain boundaries as they evolve during processing.

## ALAN G. FOX, Associate Professor:

In 1995 a Center for Materials Science and Engineering was established in the Department of Mechanical Engineering and the directorship of this Center has been assumed by Professor A.G. Fox.

Also during 1995, Professor Fox has continued his work in collaboration with the Annapolis Detachment of the Carderock Division of the Naval Surface Warfare Center on the correlations between mechanical properties and microstructure of Navy high strength steels and their weldments so that new weld consumables and parent steels for naval applications can be developed. This work has also been extended to develop a collaboration with the Naval

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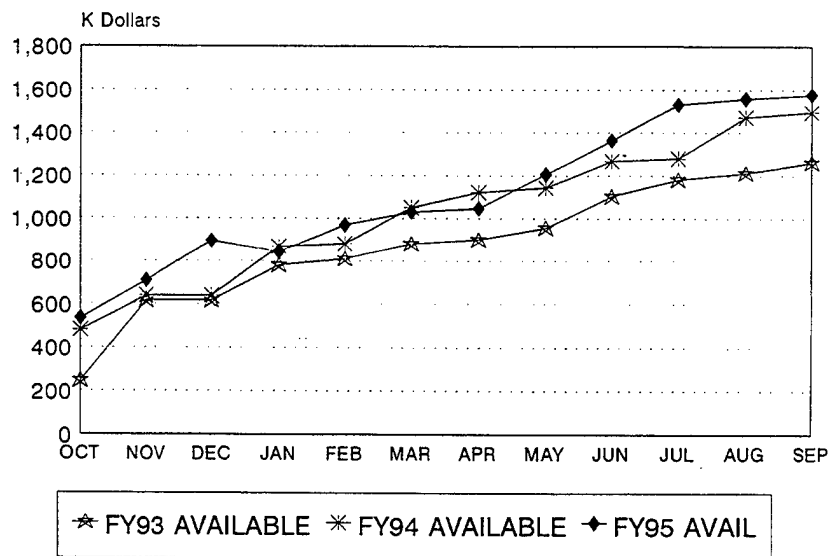
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Research Laboratory and is supported by the Office of Naval Research. As in 1994, two projects are being undertaken in collaboration with the Naval Air Warfare Center, Pax River, MD. The first involves the characterization of the hot salt corrosion of silicon carbide fiber-reinforced glass ceramic matrix composites which are potential lightweight replacements for nickel-based superalloys in high temperature aero-engine applications and the second concerns the microstructural characterization of new high temperature intermetallic alloys (including TiAl and NiAl) using new methods in x-ray and electron diffraction. This latter project is also supported by the Materials Development Branch of the Wright Patterson Airforce Base, Dayton, OH. Dr. E.S.K. Menon continues to work in Professor Fox's research group as a Research Assistant Professor working on electron and x-ray diffraction studies of intermetallic alloys and PEELS studies of the carbon distribution in weldments of Navy steels. Also during 1995, Dr. Atul Kumar continued in the group as a National Research Council Postdoctoral Associate working on studies of the corrosion of silicon carbide fiber-reinforced glass ceramic matrix composites.



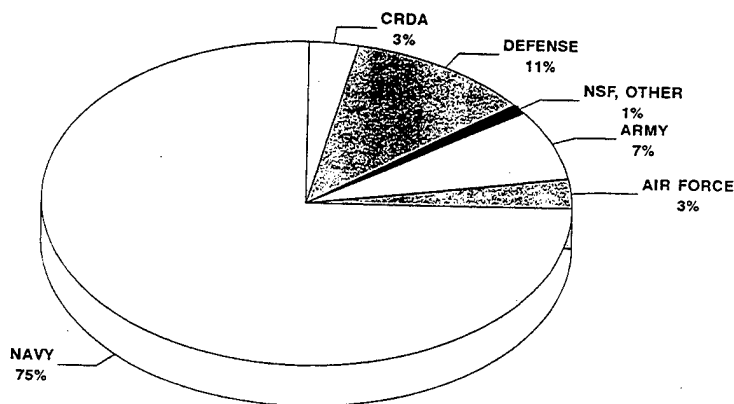
# FY95 REIMBURSABLE PROGRAM

## Department of Mechanical Engineering



**Figure 1. Reimbursable Funds Available by Fiscal Year.**

This graph shows the amount of reimbursable funding available to the department. Dollar amounts include research and academic reimbursable activities, as well as funding from Cooperative Research and Development Agreements.



**Figure 2. FY95 Reimbursable Sponsor Profile.**

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## **TOTAL SHIP SYSTEMS ANALYSIS AND ASSESSMENT METHODS**

**Charles N. Calvano, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** Improve methods for enhancing warship military effectiveness and for assessing that effectiveness, through the fostering of education and research.

**SUMMARY:** The principal objective of this program, which is the subject of a Memorandum of Agreement between NAVSEA and NPS, is to foster education and research activities on an ongoing, cooperative basis, improving methods for enhancing warship military effectiveness and for assessing that effectiveness. An emphasis on applying total ship system engineering (TSSE) methods to system development process is intended. Desired results are: improvement in the understanding of the relationship between warship vulnerability reduction and warship effectiveness; improvement of the degree to which Navy engineers understand and apply total ship systems engineering methods in their work; improvements in techniques for the integration of combat systems and supporting hull, mechanical and electrical ship systems; research which provides tools and methods to enhance the application of TSSE methods; enhanced understanding of the potential and value of simulation and modeling methods in the warship development process; and, the development of innovative total ship survivability and assessment tools and methods.

### **PUBLICATIONS:**

Calvano, C., "A Two-Stage Littoral Warfare Ship System Design," Naval Postgraduate School Technical Report, NPS-ME-95-05, December 1995.

Calvano, C., "Total Ship Systems Engineering; A Graduate Systems Engineering/Design Program," Proceedings, Fourth World Conference on Engineering Education, Vol. II, p. 67, 15-20 October 1995.

### **CONFERENCE PRESENTATIONS:**

Calvano, C., "Systems Engineering in a Ship Design Environment," Naval Sea Systems Command, March 1995.

Calvano, C., "Total Ship Systems Engineering; A Graduate Systems Engineering/Design Program," 4th Annual World Conference on Engineering Education, October 1995.

**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Measures of effectiveness, ship performance

## **DESIGN AND EVALUATION OF SLICE HULL CONCEPT**

**Charles N. Calvano, Associate Professor**

**Fotis A. Papoulias, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** Initiate studies on a new hull form, called SLICE, and evaluate its potential advantages over a more traditional SWATH hull form.

**SUMMARY:** Preliminary structural modeling of SLICE hulls indicated the ability of such ships to withstand wave loading. Comparative resistance calculations demonstrated the SLICE hulls may offer reduced resistance in relation to a comparable size SWATH, depending on the range of key parameters, such as speed, length, displacement, and hull

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separation. Systematic studies with regard to ship resistance, structural response, maneuvering properties and motions in waves indicated proper design guidelines that could help in maximizing the operation capabilities of such ships.

## **THESES DIRECTED:**

Wolkerstorfer, W.J., "A Linear Maneuvering Model for Simulation of SLICE Hulls," Master's Thesis, September 1995.

Stevens, H.W., "Resistance Scaling and Predictions of SLICE Hulls from Model Tests," Master's Thesis, September 1995.

Lesh, D.B., "Seakeeping Characteristics of SLICE Hulls: A Motion Study in Six Degrees of Freedom," Master's Thesis, September 1995

Roberts, D.J., "Structural Response of the SLICE Advanced Technology Demonstrator," Master's Thesis, June 1995.

Al-Jowder, J.A., "Comparative Resistance Calculations of SLICE/SWATH Hulls," Master's Thesis, March 1995.

Peffer, S.B., "Seakeeping Aspects of SLICE Hulls," Master's Thesis, March 1995

Rodriguez, M.A., "Structural Analysis of SLICE Hulls," Master's Thesis, March 1995.

**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** SLICE hull, ship structures, ship resistance

## **SYSTEMS ENGINEERING RESEARCH IN SUPPORT OF TWENTY-FIRST CENTURY SURFACE COMBATANT (SC 21)**

**Charles N. Calvano, Associate Professor  
Department of Mechanical Engineering  
Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** Ensure the Systems Engineering Master Plan and other systems engineering foundations for the SC-21 ship development program consist of state of the art systems engineering methods.

**SUMMARY:** This project supports the SC-21 program manager in incorporating the highest quality total ship systems engineering methods and processes in the development of the surface combatant for the 21st century. The mission needs statement for the SC-21 is a very comprehensive description of the needs the SC-21 must meet and will demand application of unprecedented levels of systems engineering ingenuity in the program to ensure the development of sound warship architecture and program methods. The principal investigator has an extensive background in exploration of systems engineering methods in the development of Navy warships. This proposal calls for the principal investigator to assist, guide, critique and evaluate the SC-21 Program Office plan for evolution of the mission needs statement to a requirements document; to provide guidance and advice to the SC-21 Program Office in the formulation of the program's Systems Engineering Master Plan; and, to support the SC-21 Program Office in developing methods to disseminate and promote understanding of its systems engineering objectives and methods.

## **OTHER:**

Letter report to the SC-21 Program Manager with specific suggestions for Systems Engineering Master Plan contents and modifications.

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**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Surface ship, surface combatant, systems engineering, ship development

## **SEA BASED DEPLOYMENT SHIP DESIGN ASSESSMENT**

**Charles N. Calvano, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: USAF Electronics Systems Center, Hanscom AFB**

**OBJECTIVE:** Ensure the viability, effectiveness, efficiency and accuracy of ship design plans for ships to be modified to carry the USAF sea-based dual-band transportable radar system.

**SUMMARY:** This program, funded in two fiscal years, is for the evaluation of designs for the modification of a ship to be used by the USAF electronic systems center (ESC) in the sea based evaluation of a dual band transportable radar system. The ESC and Lincoln laboratories are developing the radar; they will obtain ship engineering and specification preparation services from the Military Sealift Command (MSC), but wish to have an independent review of the design objectives and features by a knowledgeable ship designer. The PI will independently assess the design features developed by MSC and advise ESC as to their desirability or expected effectiveness. The PI will apply his background and expertise in ship design and in total ship systems engineering (TSSE) methods to the evaluation of this process. The PI will also pursue opportunities to use cases and/or issues from this project in his teaching and will encourage the involvement of his officer students in the exploration of appropriate engineering issues as part of their education.

### **OTHER:**

Letter report to the Electronics Systems Center containing recommendations concerning how to proceed with the design effort.

**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Surface ship, sea-borne radar

## **FORCE OVERRIDE RATE CONTROLLER FOR REMOTE ACTUATION**

**Morris Driels, Professor**

**Department of Mechanical Engineering**

**Sponsor: National Aeronautics and Space Administration, Johnson Space Center**

**OBJECTIVE:** The purpose of the project is to study new and cost effective ways to implement force reflectance in teleoperator systems

**SUMMARY:** Although the work on this project has been somewhat dormant, some progress has been made on the implementation of passive motion resistance due to feedback of external forces from a remote environment. In this scheme, the rotation of a joint is resisted by a brake such that the braking resistance (torque) is proportional to the signal from a force sensor placed in the slave part of the teleoperator. In this way, active actuation, with its accompanied size and weight, is avoided, and a small, lightweight system results.

### **THESIS DIRECTED:**

Chatfield, J., "Force Feedback for Anthropomorphic Teleoperated Mechanisms," Master's Thesis, June 1995.

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**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Human Systems Interface, Sensors

**KEYWORDS:** Teleoperation, force feedback

## **IMPROVED TARGET ACQUISITION ALGORITHMS FOR JANUS (A)**

**Morris Driels, Professor**

**Department of Mechanical Engineering.**

**Judith Lind, Adjunct Professor**

**Department of Operations Research**

**Sponsor: Training and Doctrine Analysis Command - TRAC Monterey**

**OBJECTIVE:** The goal of this project is to enhance the TRADOC Analysis Command Janus (A) combat simulation model by incorporating new algorithms and data that more closely resemble real-world target acquisition performance.

**SUMMARY:** In FY 95 work focused on implementing the perspective view generator algorithms, initially developed by TRAC contractors, on a single CPU workstation. This was accomplished early in 1995, and gave excellent visualizations of the terrain, with a frame rate of about 1-2 frames/second. Following this, the target acquisition algorithms found in ACQUIRE were implemented, showing how some of the detection parameters could now be calculated in a dynamic, rather than a static manner. Work was also done to convert the algorithms to run on parallel processing workstations, and lead to an improvement in frame rate to around 9 frames/second.

### **CONFERENCE PRESENTATION:**

Driels, M., "High Fidelity Terrain Visualization: Applications to Janus Modeling and Opportunities for Parallelism," Proceedings of 63rd MORS Symposium, Annapolis, MD, June 1995.

### **THESES DIRECTED:**

Whitney, M., "Visualization of Improved Target Acquisition Algorithm for JANUS (A)," Master's Thesis, December 1994.

Buziak, J., "Parallel Implementations of Perspective View Generator Ray Tracing Algorithms," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREAS:** Computing and Software, Human System Interfaces

**KEYWORDS:** Target acquisition, search, Janus(A), combat simulation, line of sight, human factors, human performance

## **A COMBINATIVE METHOD FOR THE ACCURATE MEASUREMENT OF STRUCTURE FACTORS AND CHARGE DENSITIES OF INTERMETALLIC ALLOYS**

**Alan G. Fox, Associate Professor**

**Sarath K. Menon, Research Assistant Professor**

**Department of Mechanical Engineering**

**Sponsors: Wright-Patterson Airforce Base and Naval Air Warfare Center - Aircraft Division**

**OBJECTIVE:** To accurately measure the low-angle structure factors of elements and intermetallic alloys by various diffraction methods so that their electronic bonding mechanisms can be investigated.

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**SUMMARY:** A knowledge of the distribution of bonding electrons in solids can give important information about their physical properties. One way to gain such knowledge is to accurately measure the low-angle structure factors by some means, and then use these to generate maps of the electron charge distributions. In the present work, electron diffraction has been used to measure the low-angle structure factors of NiAl. An electron charge distribution has been generated for this alloy and important bonding information has emerged. During 1991 x-ray diffraction work commenced on the TiAl system and in 1992 continued so that accurate values of the lattice parameters and Debye-Waller factor of TiAl were obtained. During the last quarter of 1992 and during 1993 electron diffraction measurements of the low-angle structure factors of TiAl were made on the 1.5 MeV high voltage electron microscope (HVEM) at the University of California, Berkeley and on the 3.0 MeV HVEM at CEMES/LOE du CRNS, Toulouse, France. During 1994 Dr E.S.K. Menon joined this project as a Research Assistant Professor and has continued both the x-ray and electron diffraction work. This has resulted in several publications in 1995.

## **PUBLICATIONS:**

Fox, A.G., "Low-Angle Structure Factors, Debye Temperature and Charge Density of NiAl: A Reconciliation between Experiment and First Principles Full Potential Linear Augmented Plane Wave (FLAPW) Calculations in the Local Density Approximation," Scripta Metallurgica et Materiala, Vol. 32, pp. 343-347, 1995.

Menon, E.S.K. and Fox, A.G., "Lattice Parameters and Debye-Waller Factors of  $\gamma$ -TiAl Alloys," Gamma Titanium Aluminides, Proceedings of a symposium sponsored by the Structural Materials Division of TMS held during the TMS Annual Meeting in Las Vegas, NV, edited by Y-W. Kim, R. Wagner and M. Yamaguchi and published by the Minerals, Metals and Materials Society, pp. 369-376, 13-16 February 1995.

## **CONFERENCE PRESENTATIONS:**

Fox, A.G. and Menon, E.S.K., "Structure Factors and Bonding in  $\beta$ NiAl," 1995 Hume-Rothery Symposium honoring Professor David Pettifor at the 124th TMS Annual Meeting, Las Vegas, NV, 13-16 February 1995.

Fox, A.G., "Twenty Years of Diffraction Studies on Intermetallic Compounds," 65th birthday Conference for Professor R.E. Smallman, CBE, Institute of Materials, Birmingham U.K., 27-28 April 1995.

## **OTHER:**

Menon, E.S.K. and Fox, A.G., "On the Determination of the Debye-Waller Factor and Structure Factors of NiAl by X-ray Powder Diffraction," to appear Acta Metallurgica et Materiala.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** TiAl alloys, electron diffraction, x-ray diffraction, bonding charge density

## **MICROSTRUCTURES AND MECHANICAL PROPERTIES OF HIGH-STRENGTH, LOW-ALLOY (HSLA) STEELS AND THEIR WELDMENTS**

Alan G. Fox, Associate Professor

Department of Mechanical Engineering

Sponsors: Naval Surface Warfare Center, Carderock Division, Annapolis Detachment

**OBJECTIVE:** To investigate the microstructure and mechanical properties of HY and HSLA 80-130 series steels and their weldments to evaluate new weld consumables and parent steels for Naval shipbuilding applications.

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**SUMMARY:** In recent years the US Navy has been replacing the HY80-100 series of high strength alloy steels with their high-strength, low-alloy (HSLA) equivalents. This is being done because the stringent weld pre-heat requirements associated with the HY steels are not necessary for the HSLA series. So, despite the higher manufacturing costs of high-strength, low-alloy steels, the U.S. Navy should make significant savings by changing over to HSLA or ultra low carbon bainitic (ULCB) steels for ship and submarine construction. In addition, the Navy's stringent requirement that weld metal have the same strength as the base plate presents an interesting challenge in weld wire development for both HSLA and HY steels. This project aims to support these objectives with fundamental physical metallurgy studies at NPS. Lt. A.L. Clarke, who completed a thesis in this area, received the Navy League Award in December 1995.

## **PUBLICATIONS:**

Fox, A.G. and Brothers, D.G., "The Role of Titanium in the Non-Metallic Inclusions which Nucleate Acicular Ferrite in the Submerged Arc Weld (SAW) Fusion Zones of Navy HY-100 Steel," accepted for publication in Scripta Metallurgica et Materiala, Vol. 32, pp. 1061-1066, 1995.

Fox, A.G., Vassilaros, M.J., Franke, G.L., and Wong, R.J., "Some New Ideas about the Non-metallic Inclusions in Arc Weldments in High Strength Steels," Proceedings of the 76th AWS Convention, Cleveland, OH, 3-7 April 1995.

## **CONFERENCE PRESENTATIONS:**

Blackburn, J.M., Vassilaros, M.J., and Fox, A.G., "Factors Affecting the Impact Toughness of Low Carbon Bainitic Weld Metal," 4th International Conference on Trends in Welding Research, Gatlinburg, TN, 5-8 June 1995.

Blackburn, J.M., Vassilaros, M.J., Brandemarte, A., Fox, A.G., and Franke, G.L., "The Effects of Thermal Cycling on ULCB Weld Metal," TMS Annual Meeting, Cleveland, OH, 23-26 October 1995.

Blackburn, J.M., Vassilaros, M.J., and Fox, A.G., "The Effect of Thermal Cycling on Ultra Low Carbon Bainitic Weld Metal Toughness," 76th AWS Convention, Cleveland, OH, 3-7 April 1995.

## **THESES DIRECTED:**

Reck, V., LT, USN, "Mechanical and Microstructural Properties of Ultra-Low Carbon Bainitic Steel," Master's Thesis, June 1995.

Clarke, A.L., LT, USN, "The Effect of Varying the MnO Content of the Flux Used in the Submerged Arc Welding of Navy HY-100 Steel," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** High-strength steels, welding, steel weld filler metal, ultra low carbon bainitic steels, high strength low-alloy steels

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## MICROSTRUCTURAL STUDIES OF SILICON FIBER REINFORCED GLASS-CERAMIC COMPOSITES FOR GAS TURBINE APPLICATIONS

Alan G. Fox, Associate Professor

Department of Mechanical Engineering

Sponsors: Naval Air Warfare Center - Patuxent River and Wright-Patterson Airforce Base

**OBJECTIVE:** To investigate the hot corrosion of silicon fiber reinforced glass-ceramic matrix composites.

**SUMMARY:** The US Navy and Air Force have ongoing programs of research into silicon fiber reinforced glass-ceramic matrix composites (CMCs) which have many potential uses for gas turbine components. The high strength, toughness and resistance to high temperatures and low density of CMCs could allow a considerable increase in gas turbine engine efficiency if they could be used to replace heavy metallic parts. Unfortunately, aircraft operating environments are often very severe and any CMC components developed must be resistant to high temperature environments containing salt and aviation fuel which may be rich in sulfur. This work is using electron microscopy and x-ray diffraction to elucidate the mechanisms of hot salt corrosion in lithium, calcium and magnesium aluminosilicates reinforced with silicon carbide fibers. The results of this work are helping to determine which CMCs are suitable for DoD applications. During 1995 one Masters theses was completed and Dr A. Kumar, a National Research Council Postdoctoral Research Assistant, worked on this project.

### PUBLICATIONS:

Fox, A.G., Hunt, R.K., Mardia, L.C., and Wang, S.W., "Hot Sodium Sulfate Corrosion of a Nicalon Silicon Carbide Fiber-Reinforced Lithium Aluminosilicate Glass-Ceramic Matrix Composite," Journal of Materials Science, Vol. 30, pp. 6161-6170, 1995.

Kumar, A., Oppici, M.A., Fox, A.G., and Wang, S.W., "The Effects of Hot Corrosion on the Microstructure of a Silicon Carbide Fiber-Reinforced Calcium Aluminosilicate, High Temperature Ceramic Matrix Composites I," Proceedings of the Second International Conference on High-Temperature Ceramic-Matrix Composites, Santa Barbara, CA, Ceramic Transactions, Vol. 57, pp. 455-458, 21-24 August 1995.

### THESIS DIRECTED:

Oppici, M.A., LT, USN, "Sodium Sulfate Hot Corrosion of Silicon Carbide Fiber-Reinforced Calcium Aluminosilicate," Master's Thesis, March 1995.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** Hot corrosion, ceramic matrix composites, electron microscopy, x-ray diffraction

## CONVECTIVE HEAT TRANSFER INDUCED BY STRONG ACOUSTIC FIELDS

Ashok Gopinath, Assistant Professor

Department of Mechanical Engineering

Sponsor: Naval Postgraduate School

**OBJECTIVE:** To develop correlations for calculating convective heat transfer rates induced by strong acoustic fields around a cylinder.

**SUMMARY:** This work was motivated by the need to provide a better understanding of the heat transfer behavior in internal oscillatory flows with application to the improvement of the design of heat exchangers in thermoacoustic engines. As per the work proposed, an experimental rig was constructed to first explore geometries of fundamental



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interest, such as a cylinder, which make up one of the basic component shapes in a heat exchanger. Two students from the Space Systems curriculum were involved in the design and construction of this apparatus.

The rig had a cylindrical cartridge heater (with a built-in thermocouple) positioned along the diameter of a cylindrical resonant duct in which a plane resonant standing wave was excited using a high-power compression driver. Power and temperature measurements at steady state provided the necessary data to deduce the heat transfer coefficients. A large amount of data gathered by one of the students should be valuable in future heat exchanger design. The other student simultaneously conducted a theoretical analysis of the thermoacoustic streaming phenomenon responsible for generating the time-averaged heat transfer effects in a thermoacoustic engine. Basic parallel plate geometry in a high-intensity zero-mean oscillatory flow was considered, which provided considerable insight into the effects of gap width, and would be of use in determining the optimum gap width in the stack of a thermoacoustic engine.

This project is being continued into FY96 to address other shapes and parameter regimes of practical interest that were not considered in the first phase of the project.

## **THESES DIRECTED:**

Harder, D.H., "Convective Heat Transfer from a Cylinder in a Strong Acoustic Field," Master's Thesis, December 1995.

Tait, N.L., "Recovery Factors in Zero-Mean Internal Oscillatory Flows," Master's Thesis, December 1995.

## **OTHER:**

Gopinath, A. and Harder, D. H., "Convective Heat Transfer from a Cylinder in a Strong Acoustic Field," submitted for publication.

Gopinath, A. and Tait, N.L., "Recovery Factors in Zero-Mean Internal Oscillatory Flows," being prepared for publication.

**DOD KEY TECHNOLOGY AREAS:** Environmental Quality, Modeling and Simulation

**KEYWORDS:** Thermoacoustics, acoustic streaming, heat transfer correlations, modeling and simulation, recovery factors, oscillatory flows

## **FREQUENCY DOMAIN METHODS IN STRUCTURAL SYNTHESIS AND IDENTIFICATION**

**Joshua H. Gordis, Assistant Professor  
Department of Mechanical Engineering  
Sponsor: Naval Postgraduate School**

**OBJECTIVE:** This project is concerned with the theoretical development of frequency domain and sensitivity-based theories for structural system identification. The theories are based on a previously developed theory for frequency domain structural synthesis.

**SUMMARY:** This research concerns the development and validation through practical application of sensitivity-based and frequency domain theories for structural system identification and structural damage detection. The frequency domain theory avoids fundamental limitations associated with modal-based methods by the elimination of modal parameter estimation and modal truncation errors, and by the direct treatment of the errors associated with instrumenting the test specimen with a finite number of response measurement transducers. Under development is the necessary theory for the practical identification of an impedance error spectra for a linear math model of a dynamic system and the

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subsequent decomposition of the impedance error spectra into the constituent error spectra of mass, stiffness, and (non-proportional) damping. Focusing on spatially incomplete identification, the research is investigating the localization of model errors and the relationship between the error spectra identified from spatially incomplete test data and the "true" parameter errors in the original, unreduced analytic model. The research will introduce non-traditional physical coordinate model reduction methods as well as traditional optimization techniques to cope with the limited amount of data typically generated in a vibration test. Experimental studies with simple yet representative structures are underway.

## CONFERENCE PRESENTATION:

Gordis, J.H., "Omitted Coordinate Systems and Artificial Constraints in Spatially Incomplete Identification," 1995 AIAA/ASME/ASCE/AHS/ACS Structures, Structural Dynamics, and Materials Conference, New Orleans, LA, 1995.

## THESES DIRECTED:

Renken, J., "Optimal Solution Selection or Sensitivity-Based Finite Element Model Updating and Structural Damage Detection," Master's Thesis, December 1995.

Johnson, R., "Frequency Domain Structural Identification," Master's Thesis, June 1995.

## OTHER:

Gordis, J.H., "On the Analytic Disassembly of Structural Matrices," submitted to Modal Analysis.

**DOD KEY TECHNOLOGY AREA:** Other (Design Automation)

**KEYWORDS:** Structural Dynamics, frequency domain, synthesis, identification

## TIME DOMAIN METHODS IN STRUCTURAL SYNTHESIS AND IDENTIFICATION

Joshua H. Gordis, Assistant Professor  
Department of Mechanical Engineering  
Sponsor: Naval Postgraduate School

**OBJECTIVE:** This project is concerned with the theoretical development and computational implementation of a time domain theory for structural synthesis.

**SUMMARY:** This research concerns the development of a time domain theory for structural synthesis. This new theory provides the previously unavailable capability of performing exact transient structural synthesis, regardless of damping. The method is based on Volterra integral equations derived from the convolution integral which describe substructure coupling and structural modification. The numerical solution of the integral equations yields a triangular linear system which is solved for the synthesized system transient responses/coupling forces, with no factorization or eigensolution required.

## PUBLICATION:

Gordis, J.H., "Integral Equation Formulation for Transient Structural Synthesis," AIAA Journal, Vol. 33, No. 2, 1995.

**DOD KEY TECHNOLOGY AREA:** Other (Design Automation)

**KEYWORDS:** Structural Dynamics, time domain, synthesis, identification

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## **STRUCTURAL DYNAMICS OF THE RAH-66 COMANCHE HELICOPTER**

**Joshua H. Gordis, Assistant Professor**

**Department of Mechanical Engineering**

**Sponsor: U.S. Army Aviation and Technology Command**

**OBJECTIVE:** Technical support is provided to the US Army Aviation and Technology Command, for the structural dynamics and vibration of the RAH-66 Comanche.

**SUMMARY:** The RAH-66 Comanche helicopter is the US Army's attack helicopter for the 21st Century. During 1995, the Comanche began a program of ground vibration and flight tests, intended to validate structural dynamic performance of the airframe and to demonstrate the helicopter's performance characteristics. These tests typically uncover dynamics problems with rotor-fuselage coupling and forced response. In order to ensure the survival of the Comanche program, these

problems, when discovered, must be quickly resolved. This effort provides rapid technical support to the Comanche Program, to resolve structural dynamics problems. A proposal for continued FY96 funding has been submitted.

**DOD KEY TECHNOLOGY AREA:** Air Vehicles

**KEYWORDS:** Helicopter, comanche, structural dynamics

## **BUGS: BASIC UXO GATHERING SYSTEM - SIMULATOR DEVELOPMENT**

**Anthony J. Healey, Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Ordnance Technical Center**

**OBJECTIVE:** This work is being undertaken to provide a graphics based simulator and a rapid simulation capability for the clearance performance for the BUGS system for UXO Gathering. Both the vizualization of the controlled motion of multiple cooperating vehicles and the evaluation of various system concepts were studied.

**SUMMARY:** The graphics simulator code runs on a high end SGI workstation currently an ONYX Reality Engine workstation and has been developed using the "inventor" and "performer" tool kit. It is planned to use the simulator as a training tool for the US Army / Marine Corps to evaluate sensor technology as well as control methodologies in semi realistic environments in relation to the performance of the overall BUGS system concepts for land based ordnance clearance operations. The simulator is built around a terrain base taken from the Marine Corps 29 Palms facility and a small subset of that data base has been selected as a test site for evaluation of clearance operations. Vegetation has been included as uniformly distributed randomly dispersed objects added to the data base. Munitions simulated include Mk 118 anti-personnel munitions, softball and baseball munitions that would have been dispensed from an airborne canister. These munitions are then randomly distributed around a nominal center with an average density that is selectable by the user. Clearance operations are then simulated by a fleet of walking machine BUGS that can be controlled to a speed, heading and altitude above ground command. The walking machines are rendered as full kinematically faithful hexapods walking with a double tripod fixed gait, where each bug has an arm (boom) to support a camera, tactile, or magnetic sensor. The sensor has a defines radius of detection so that if a munition is encountered, a command is registered in the machine controller to manipulate the boom and retrieve the object. Search patterns can be simulated that are directed exhaustive searches if motion sensors are presumed to have sufficient accuracy on board the machines, or random searches if no motion sensors would be presumed to be available. The characteristics of random versus exhaustive search have been established as part of this research, and the influence of various levels of navigation sensor accuracy and inter bug communication on search effectiveness are being sought. Recently, questions concerning the comparison of random search as opposed to supervised autonomous vehicle searches in PUCA operations are being analysed.

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## **PUBLICATION:**

Healey, A.J., McMillan, S., Jenkins, D., McGhee, R.B., "BUGS: Basic UXO Gathering System," Proceedings of the Symposium on Autonomous Vehicles in Mine Countermeasures, Monterey, CA, 4-7 April 1995.

## **THESES DIRECTED:**

Jenkins, D.A., "BUGS: Basic Unexploded Ordnance Gathering System: Effectiveness of Small Cheap Robotics," Master's Thesis, June 1995.

Webber, W., "Magnetic Inductive Sensor Applications for Robotic Ordnance Detection and Recovery," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Mine warfare, Robotics)

**KEYWORDS:** Robotics, modeling and simulation, mine warfare

## **INVESTIGATION OF CONVECTIVE HEAT TRANSFER IN "FLOW THROUGH" MODULES AND INTERNALLY FINNED CHANNELS**

**Matthew D. Kelleher, Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Surface Warfare Center - Crane Division**

**OBJECTIVE:** The objectives of this investigation were to investigate the convective heat transfer in liquid flow through modules and the internally finned channels found in these modules and to develop computational modeling capabilities to predict the performance of flow through modules.

**SUMMARY:** The investigation used a Standard Electronic Module, format E (SEM-E) size flow through module with a dielectric polyalphaolefin as the liquid coolant. One surface of the module was populated with six etched foil heaters placed over the flow path. Thermocouples attached to the module surface and also placed in the inlet and outlet tubing provided data to quantify module effectiveness and heat transfer characteristics for a variety of power inputs and liquid coolant flow rates. Work has also been conducted to investigate the details of the heat transfer process internal to the flow through module. To carry out this study, a ten times scaled up model of the offset plate finned array structure of the internal passages of the flow through module was constructed. Heat transfer and flow visualization data have been obtained for this model.

## **PUBLICATION:**

Mukutmoni, D., Joshi, Y., and Kelleher, M.D., "Computations for a Three-By-Three Array of Protrusions Cooled by Liquid Immersion: Effects of Substrate," Journal of Electronics Packaging, December 1995.

## **CONFERENCE PRESENTATION:**

Mukutmoni, D., Yang, K.T., and Kelleher, M.D., "Thermal Convection in a Small Box Heated from Below for a High Prandtl Number Fluid," 4th ASME/JSME Thermal Engineering Joint Conference, Maui, HI, March 1995.

## **THESES DIRECTED:**

Yeniçeri, E., LTJG, Turkish Navy, "Heat Transfer Studies of a Flow Through Module for Electronics Cooling," Master's Thesis, September 1995.

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Komral, A., LTJG, Turkish Navy, "Heat Transfer Studies on a Rectangular Channel with Offset Strip Fins," Master's Thesis, September 1995.

Turk, U., LTJG, Turkish Navy, "Boiling of Highly Wetting Liquids in Oscillatory Flow," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Other (Electronics Cooling)

**KEYWORDS:** Electronics cooling, heat transfer

## BIOMECHANICAL STUDY OF HUMAN KNEE JOINT

Young W. Kwon, Associate Professor  
Department of Mechanical Engineering  
Sponsor: Naval Medical Center

**OBJECTIVE:** The goal of this project was to understand knee motions before and after ligament injury as well as after ligament reconstruction, and to evaluate different surgical techniques. This year emphasis was placed on anterior cruciate ligament (ACL) deficient knees, reconstructed knees and total reconstruction knees. In addition, osteonecrosis of femoral head was studied.

**SUMMARY:** This was a continuing project from previous years. A six degree of freedom test jig was developed to continuously measure the motions of loaded cadaver human knees without constraint at the tibiofemoral joint through a range of motion from zero to 110 degrees of flexion. Several conditions were studied. Loading conditions were varied to simulate the natural body forces (i.e. the normal condition) and quadriceps-deficient condition. The range of motion in which the anterior cruciate ligament (ACL) was the primary restraint to anterior tibial translation was determined. The effect of ACL insufficiency on the kinematics of the human knee was investigated by comparing the kinematics of the knee specimens in the intact state with the kinematics obtained after the ACL was surgically severed. Finally, the effect of total knee replacement on kinematics was investigated. Two different surgical techniques were compared: PCL-retaining and PCL-sacrificing techniques. Further, static and dynamic testing as well as numerical simulation were performed to examine the injury of the core-drilled femoral heads.

### PUBLICATIONS:

Adkison, D., DeMaio, M., Kwon, Y.W., and Scholfield, J., "Continuous Motion Kinematics of the Intact and PCL-Deficient Knee," Annual Meeting of Arthroscopic Association of North America, San Francisco, CA, 1995.

DeMaio, M., Adkison, D. P., and Kwon, Y.W., "Continuous Motion Kinematics in the Loaded Human Cadaver Knee: A Comparison Between the Posterior Cruciate Intact, Deficient, and Reconstructed States," American Orthopaedic Society for Sports Medicine, Toronto, Ontario, Canada, July 1995. (One of Top Ten Papers Chosen for 1995 AOSSM Annual Meeting for research award.)

### OTHER:

Romero, N., "A New Kinematic Model for the Study of the Role of the Anterior Cruciate Ligament (ACL) in Human Knee Motion," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Biomedical

**KEYWORDS:** Biomechanics, knee kinematics, Anterior Cruciate Ligament (ACL)

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## **STUDIES ON DYNAMIC INTERACTION BETWEEN PRESSURE HULL AND INTERNAL STRUCTURE SUBJECTED TO UNDERWATER EXPLOSION**

**Young W. Kwon, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Surface Warfare Center - Carderock Division**

**OBJECTIVE:** The goal of this project was to develop an efficient finite element modeling technique for submerged stiffened shell structures subjected to underwater explosion. This was a continuing work from the last year.

**SUMMARY:** The study was conducted to develop simple and efficient numerical models to predict the dynamic behavior of submerged structures exposed to underwater shock. The simplified models could save not only computing times but also man hours without sacrificing the solution accuracy. To this end, smearing techniques were used to eliminate detailed stiffeners in the plate and shell structures. The study showed some threshold values of the stiffness ratio of the base plate/shell structure to the total stiffeners. If the stiffness ratio is lower than the threshold value, the global smearing model might produce erroneous results. In this case, local smearing technique was recommended. SOR (Surface Of Revolution) beam elements as well as interfacing the SOR beam elements with cylindrical structures were studied to simplify stiffened cylindrical structures. Even if there was difference in the local deformation and/or local response among the original detailed model and simplified models, their overall responses were very close. As a result, a detailed model could be simplified using the simplified models at selective portions of the structure.

### **THESIS DIRECTED:**

Burgio, R. B., "Modeling and Computer Simulation of the Dynamic Response and Failure of Composite Structures Subjected to Shock Loading," Master's Thesis and Engineer's Degree, June 1995. (NAVSEA Award)

**DOD KEY TECHNOLOGY AREAS:** Materials, Processes and Structures, Modeling and Simulation

**KEYWORDS:** Model simplification technique, finite element technique, underwater explosion

## **DAMAGE AND FAILURE MODELING IN COMPOSITE STRUCTURES**

**Young W. Kwon, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Unfunded**

**OBJECTIVE:** The objective of this project was to develop a damage/failure model which could describe progressive damage and predict the failure modes and failure strength of laminated fibrous composite structures.

**SUMMARY:** Even if laminated fibrous composite structures have complicated damage/failure modes at the macromechanical level, the damage/failure modes can be simplified at the micromechanical level where damage/failure modes are fiber breakage, matrix cracking, and fiber/matrix interface debonding. As a result, it is more intuitive and physical to describe and predict damage/failure of fibrous composites using the micromechanical parameters. To this end, a micro/macromechanical damage/failure model was introduced to simulate and predict those damage/failure modes in fibrous composite structures. Eventually, ultimate failure loads could be predicted for a general composite structure.

### **PUBLICATIONS:**

Kwon, Y.W. and Berner, J. M., "Micromechanics Model for Damage and Failure Analyses of Laminated Fibrous Composites," Engineering Fracture Mechanics, Vol. 52, No. 2, pp. 231-242, 1995.

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Kwon, Y.W. and Hamilton, B.H., "Micro/Macro-Analysis of Damage Evolution in Plate Bending of Composites," Recent Advances in Solids and Structures-1995, PVP-Vol. 321/NE-Vol. 18, pp. 1-9, 1995.

## THESES DIRECTED:

Cheng, C.-C., "3-D Finite Element Method for Micromechanical Analysis in Fibrous Composite Material," Master's Thesis, June 1995.

Guo, J.-Y., "Simplified Micromechanical Models for Analysis of Interface Debonding in a Fibrous Composite," Master's Thesis, December 1995.

## OTHER:

Kwon, Y.W. and Berner, J. M., "Matrix Damage Analysis of Fibrous Composites: Effects of Thermal Residual Stresses and Layer Sequences," accepted for publication in Structural Engineering Review.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** Fibrous composite structure, damage and failure, micro/macromechanics model

## COMPRESSIVE FAILURE OF SANDWICH COMPOSITES

Young W. Kwon, Associate Professor  
Department of Mechanical Engineering  
Sponsor: Unfunded

**OBJECTIVE:** The objective of this project was to investigate the compressive and/or impact failure of sandwich composite structures with various initial defects such as holes and delamination cracks.

**SUMMARY:** Compression and/or impact failures of symmetric or non-symmetric sandwich composites were investigated using experimental and analytical studies. Symmetric sandwich composites had carbon fiber/epoxy skins and foam core while non-symmetric sandwich composites had GRP and titanium skins and honeycomb core. The sandwich specimens had holes and/or delamination cracks between the skin and core, and they were subjected to compressive edge loading or side impact loading. Different core thicknesses of sandwich specimens were considered, and hole sizes and locations were varied to examine their effects on the compression failure. The study included compression of delaminated specimens, too. In order to better understand the failure mechanism, a numerical study was also conducted. Major modes of failure were core shearing, delamination, and skin fracture. Depending on the given parameter, failure mode was different. The study examined the transition of the failure mode from one kind to another depending on the variation of the parameters such as delamination and hole sizes and locations.

## PUBLICATIONS:

Kwon, Y.W., Murphy, M.C., and Castelli, V., "Buckling of Unbalanced, Sandwich Panels With Titanium and GRP Skins," Journal of Pressure Vessel Technology, ASME Transactions, Vol. 117, No. 1, 1995, pp.40-44.

Kwon, Y.W. and Yoon, S.-H., "Impact on Sandwich Composites With Two Different Face Materials," Canadian Congress of Applied Mechanics, Victoria, Vancouver, Canada, May 1995.

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## THESES DIRECTED:

Clawson, A., "Experimental Study of Delaminated Sandwich Composite Subject to Impact and/or Compression Loading," Master's Thesis, June 1995.

Sistare, P. J., "A Study of Failure in Carbon/Foam Sandwich Composites With Stress Concentration," Master's Thesis, September 1995.

Wojcik, G.W., "Finite Element Modeling of Sandwich Composite Structures Subject to Low Velocity Impact and Delamination," Master's Thesis, December 1995.

## OTHER:

Kwon, Y.W. and Aygunes, H., "Dynamic Finite Element Analysis of Laminated Beams With Delamination Cracks Using Contact-Impact Conditions," accepted for publication in Computers and Structures.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** Unbalanced sandwich composite, compressive failure, impact loading

## GRAIN BOUNDARY CHARACTER AND SUPERPLASTICITY

Terry R. McNelley, Professor

Department of Mechanical Engineering

Sponsor: Office of Naval Research

**OBJECTIVE:** The goal of this program is to study the role of grain boundaries in fine-grained, superplastic aluminum alloys and the development of such grain boundaries during thermomechanical processing of these materials.

**SUMMARY:** Electron back scatter pattern (EBSP) imaging with computer-aided analysis has been employed to examine the undeformed grip and deformed gage sections from tensile specimens of an Al-10Mg-0.1Zr alloy. Prior thermomechanical processing (TMP) schedules differed only in the duration of the interpass anneal (IPA) time between successive rolling passes. Microtexture analysis revealed the same texture components, primarily brass and S, in the undeformed gage while texture sharpness decreased without the appearance of new components in the deformed gage sections. Material processed with a prolonged IPA time (30 mins.) exhibited a highly superplastic response and contained a high proportion of boundaries of 5-15 misorientation. With a short IPA time (5 mins.) the material exhibited lower superplastic elongations and contained higher order twin boundaries suggesting that the twin-chain mechanism is active during TMP. Observed differences in tensile behavior is primarily due to the development of the 5-15 boundaries by extended recovery during the TMP of the more ductile material.

## PUBLICATIONS:

Crooks, R., McNelley, T.R., and Kalu, P.N., "Microstructural Development in a Superplastic P/M 7064 Alloy," Proceeding of 4th International Conference on Aluminum Alloys: Their Physical and Mechanical Properties, Vol. III, T. H. Sanders and E. A. Starke, Jr. (eds.), The Georgia Institute of Technology, Atlanta, GA, pp. 244-251, 1995.

McNelley, T.R. and Hales, S.J., "Grain Boundary Misorientation Distribution and Superplasticity in Al-10Mg-0.1Zr," Superplasticity and Superplastic Forming - 1995, A.K. Ghosh and T. R. Bieler (eds.), The Metallurgical Society, Warrendale, PA, pp. 57-66, 1995.



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McNelley, T.R. and McMahon, M.E., "An Investigation by Interactive EBSP Analysis of Processing and Superplasticity in an Aluminum-Magnesium Alloy," to appear in Metallurgical and Materials Transactions, March 1996.

## CONFERENCE PRESENTATIONS:

McNelley, T.R., "Processing and Superplasticity in Al-Mg Alloys," NSF/DoE Workshop on Basic Research Needs for Vehicles of the Future, New Orleans, LA, 6 January 1995.

Crooks, R., McNelley, T.R., Kalu, P.N., and Hales, S.J., "Grain Boundary Misorientation Distribution and Superplasticity in Al-10Mg-0.1Zr," Symposium on Superplasticity and Superplastic Forming, 124th Meeting of TMS, Las Vegas, NV, 13 February 1995.

McMahon, M.E. and McNelley, T.R., "Thermomechanical Processing and Grain Boundary Character in Superplastic Al-10Mg-0.1Zr," Symposium on Forming of Sheet Materials, Annual Fall Meeting of ASM/TMS, Cleveland, OH, 31 October 1995

## THESES DIRECTED:

Peet, B.B., "Processing and Superplasticity in Aluminum Alloy 2519," Master's Thesis, March 1995.

Stancy, S.L., "Assessment of Grain Refinement by Microtexture Analysis in Thermomechanically Processed Al 2519 Alloy," Master's Thesis, December 1995.

## OTHER:

McNelley, T.R. and McMahon, M.E., "Analyzing Superplastic Microstructures Using Interactive EBSP Methods," Journal of the Minerals, Metals and Materials Society, Vol. 48, No. 2, p.58, to appear in February 1996.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** Aluminum, superplasticity, recrystallization, grain boundaries, thermomechanical processing

## A KNOWLEDGE-BASED APPROACH TO FRACTURE TOUGHNESS IMPROVEMENT VIA PROCESSING FOR PARTICULATE-REINFORCED ALUMINUM METAL MATRIX COMPOSITES

Terry R. McNelley, Professor

Department of Mechanical Engineering

Sponsors: U.S. Army Research Office and Army Research Laboratory

**OBJECTIVE:** The goal of this program is obtain improved combinations of strength, ductility and toughness in Al-based metal-matrix composite materials by thermomechanical processing.

**SUMMARY:** Discontinuously reinforced Al matrix composite materials have many attractive properties but lack adequate ductility and toughness for many applications. Dramatic improvements in composite ductility have been attained in extruded 6061 Al-Al<sub>2</sub>O<sub>3</sub> processed using methods designed to redistribute the Al<sub>2</sub>O<sub>3</sub> particles as well as achieve a fully recrystallized matrix grain structure via particle-stimulated nucleation of recrystallization. Further improvements in ductility have been obtained with use of controlled heat treatments on processed material. The influence of deformation temperature on redistribution of particles during processing has been investigated by controlled

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deformation of samples in a channel die. Fracture toughness improvements in extruded powder metallurgy 6092 Al-SiC material have been demonstrated and strength-toughness combinations equivalent to those of the unreinforced matrix alloy have been attained.

## **PUBLICATION:**

McNelley, T.R. and Shelton, D.K., "Microstructural Control and Ductility Improvement via Processing of Particle-Reinforced 6061 Aluminum MMC Extrusions," Proceedings of the 17th Annual DoD Symposium on Metal Matrix Composites, H. M. Berkowitz (ed.), DoD Metal Matrix Composites Information Analysis Center, Purdue University, W. Lafayette, IN, 1995.

## **CONFERENCE PRESENTATIONS:**

McNelley, T.R. and Shelton, D.K., "Microstructural Control and Ductility Improvement via Processing of Particle-Reinforced 6061 Aluminum MMC Extrusions," 17th Annual Metal Matrix Composites Working Group Meeting, Salt Lake City, UT, 8 February 1995

Dutta, I., and McNelley, T.R., "An Investigation of the Effect of Post-Fabrication Processing on Microstructure and Properties of a SiC<sub>p</sub> - 6092 Al Composite," 125th Annual Meeting of TMS, Anaheim, CA, 6 February 1996

## **THESIS DIRECTED:**

Ballou, M.A., "The Effect of Thermomechanical Processing on the Tensile Properties and Microstructure of a 6061 Al-Al<sub>2</sub>O<sub>3</sub> Metal Matrix Composite," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** Metal-matrix composites, processing, ductility, particle distribution, grain refinement

## **CONTINUOUS MEASUREMENT OF AGING USING EDDY CURRENT SENSORS DURING HEAT TREATMENT OF PRECIPITATION HARDENING ALLOYS**

**Terry R. McNelley, Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Air Warfare Center - Aircraft Division**

**OBJECTIVE:** The goal of this program is the development of sensors for the continuous measurement of the aging response during heat treatment of a precipitation hardening alloy. Intelligent processing requires such a sensor to monitor material response in real time and provide input to a controller.

**SUMMARY:** This research has involved the development of a sensor system for the continuous monitoring of the aging response of 7075 aluminum alloy during intelligent heat treatment of the material. Intelligent processing requires sensors to monitor material response in real time. A sensor consisting of two spiral-wound probes and a bridge circuit with a bridge carrier amplifier (BCA) has been used to obtain data reflecting the changing resistivity of 7075 Aluminum during either isothermal or multi-step aging treatments. Transient effects during initial rapid heating to test temperature as well as during slower temperature excursions associated with multi-step treatments have been characterized. Calibration procedures have been developed to allow direct calculation of ambient temperature resistivity from BCA voltage output during isothermal aging treatments and hardness data were correlated with the resistivity data. Sensors capable of operation at temperatures up to 230° C will also be fabricated.

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## **THESIS DIRECTED:**

Hall, R.A., "Sensor Development for Intelligent Processing of Age Hardenable Aluminum Alloys," Master's Thesis, March 1995.

## **OTHER:**

Thesis expected March 1996: James, B., "Sensor Calibration for Resistivity Determination during Isothermal Age Hardening of Aluminum Alloys."

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** Intelligent processing, heat treating, aluminum alloys

## **ROTORDYNAMICS AND MAGNETIC BEARING TEST FACILITIES**

**Knox T. Millsaps, Assistant Professor**  
**Department of Mechanical Engineering**  
**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** To investigate methods to reduce lateral vibrations of high speed rotors.

**SUMMARY:** Methods to reduce vibration of rotors are being investigated. An analytical model was developed which models the long slender rotor of the experimental facility. This model contains linear, direct and cross stiffness and damping which result from the bearing dynamics. Using this model, the cause of split resonance and backward whirl, that occurs near critical speed, has been identified as being the result of non-symmetric direct stiffness. This was induced by gravity and not bearing non-circularity as previously thought. It was found that slightly non-symmetric bearings had an adverse impact on the maximum radial response. However, large differences in direct stiffnesses could reduce the maximum response. An analytical and experimental investigation of the response of accelerating rotors was done. Preliminary results suggest that it is possible to schedule acceleration, to minimize lateral deflections as the rotor transits through critical speed.

## **THESES DIRECTED:**

Vejvoda, C.E., "Analytic and Experimental Investigation of Rotordynamic Response and Backward Whirl induced by Split Resonance," Master's Thesis, December 1994.

Reed, G., "Analytic and Experimental Investigation of an Accelerating Rotor," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Other (Propulsion and Energy Conversion)

**KEYWORDS:** Rotordynamics, split-resonance, backward whirl, gravity effects, bearings, accelerating response, acceleration scheduling

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## ADVANCED GAS TURBINE RESEARCH PROGRAMS

Knox T. Millsaps, Assistant Professor  
Department of Mechanical Engineering  
Sponsor: Naval Sea Systems Command

**OBJECTIVE:** To assess ways in which the Naval Postgraduate School can support advanced machinery research and development programs at the Naval Sea Systems Command. Also, to consult on current programs, such as the ICR gas turbine engine.

**SUMMARY:** June through August of 1995 was spent working as a consultant to the Naval Sea Systems Command in Washington D.C., NSWC Annapolis, NSWC Carderock, NSWC Philadelphia, NUWC New London. An assessment was made on specific ways to enhance research relationships among NPS, NAVSEA and the various Navy Laboratories. Specific technical areas were identified, where the expertise of NPS should be utilized to enhance NAVSEA's R&D programs. A design investigation, review and report on potential problems with acid condensation in gas turbine exhausts for the Navy's new gas turbine engine, the ICR, were done. Several other tasks supporting the ICR, such as advising on the regenerator test installation facility, were provided. Preliminary work on the next generation slot eductor system for the SC-21 was initiated.

### PUBLICATION:

Millsaps, K.T., "ICR Design Report - U. S. Navy Experience with Acid Condensation in Gas Turbine Exhaust Systems," 16 September 1995.

**DOD KEY TECHNOLOGY AREA:** Other (Propulsion and Energy Conversion)

**KEYWORDS:** Gas turbines, ICR, slot eductors, IR suppression, diesels, condition based maintenance, free rotor muffler

## INTERNATIONAL GAS TURBINE EMISSION PANEL

Knox T. Millsaps, Assistant Professor  
Department of Mechanical Engineering  
Sponsor: Naval Sea Systems Command

**OBJECTIVE:** To organize and chair an expert panel for the IGTI conference on marine gas turbine emissions.

**SUMMARY:** The IGTI Marine Committee Executive Board, directed an expert panel to discuss the state of the art in marine gas turbine emissions. Representatives from government (EPA, CARB, IMO) industry (GE, Allison) and universities were brought together at the IGTI 1995 meeting in Houston. Technological and regulatory issues were discussed. The principle investigator organized and chaired the session.

### CONFERENCE PRESENTATION:

Millsaps, K. T., "State of Gas Turbine Emission Regulation for NO<sub>x</sub>," IGTI Keynote Panel, International Gas Turbine Conference, Houston, TX, June 1995.

**DOD KEY TECHNOLOGY AREA:** Other (Propulsion and Energy Conversion)

**KEYWORDS:** Emissions, NO<sub>x</sub>, regulations

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## **CONDITION BASED MAINTENANCE FOR DIESEL ENGINES**

**Knox T. Millsaps, Assistant Professor**

**Department of Mechanical Engineering**

**Sponsors: Naval Postgraduate School and Naval Sea Systems Command**

**OBJECTIVE:** To investigate methods for assessing the condition of a diesel engine utilizing high response instrumentation and advanced signal processing.

**SUMMARY:** Methods for predicting the condition of a diesel engine are being developed. Specifically, an engine cycle analyzer is being used to assess induced combustion faults and to localize. Techniques based on advanced signal processing, such as Joint-Time-Frequency-Analysis are being created. Fuel injection timing faults have been localized using this method.

### **THESIS DIRECTED:**

Armstrong, R.A., "Advanced Signal Processing for CBM of Diesel Engines," Master's and Mechanical Engineering Thesis, December 1995.

### **OTHER:**

Abstract submitted to the SAE Congress, Detroit, MI, January 1997.

**DOD KEY TECHNOLOGY AREA:** Other (Propulsion and Energy Conversion)

**KEYWORDS:** Condition based maintenance, diesel, engine cycle analyzer, fuel injection faults

## **DEVELOPMENT OF A FLEXIBLE SURGICAL ROBOTIC ARM**

**Ranjan Mukherjee, Assistant Professor**

**Department of Mechanical Engineering**

**Sponsor: Advanced Research Projects Agency**

**OBJECTIVE:** The objective of this research is to develop a flexible surgical robotic manipulator which will aid in minimally invasive surgery.

**SUMMARY:** A novel mechanical linkage was designed that provides a high degree of articulation inspite of having a single degree of freedom. This linkage will form the articulated tool or the robotic manipulator that will aid in minimally invasive surgical procedures. The articulated linkage can be miniaturized such that it can pass through a standard trocar sleeve. It can provide dexterity and it can apply sufficiently large forces as required during surgical procedures.

### **CONFERENCE PRESENTATION:**

Mukherjee, R. and Thiel, R.A., "An Actuation System for the Control of Multiple Shape Memory Alloy Actuators," Proceeding of 3rd IASTED Conference on Robotics and Manufacturing, Cancun, Mexico, pp. 73-76, June 1995.

### **THESES DIRECTED:**

Parkhurst, W.T., LT, USN, "Design of a Superelastic Alloy Actuator for a Minimally Invasive Surgical Manipulator," Master's Thesis, December 1994.

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Conway, C.D., LT, USN, "Analytical Analysis of the Tip Displacement of a Bourdon Tube," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREAS:** Battlespace Environment, Biomedical, Manufacturing Science and Technology

**KEYWORDS:** Minimally invasive surgery, dexterous manipulation, trocar sleeve, articulated mechanism

## REPEATABILITY IN NONHOLONOMIC MECHANICAL SYSTEMS

**Ranjan Mukherjee, Assistant Professor**

**Department of Mechanical Engineering**

**Sponsor: National Science Foundation**

**OBJECTIVE:** There are certain nonholonomic systems for which certain closed paths in the space of the independent variables do not produce any net change of the dependent variables. These trajectories are like "holonomic loops" over which the nonholonomic system exhibits holonomic behavior globally. Research is aimed at planning such drift-free trajectories for nonholonomic systems.

**SUMMARY:** The repeatability problem has been studied in a planar space robot and a three link redundant manipulator under pseudoinverse control. Preliminary studies indicate that repeatability can be achieved in the absence of integrability of the nonholonomic constraints of motion. The motion planning and control problems of a nonholonomic two-wheeled mobile robot have also been researched. The mobile robot motion planning problem has been addressed in the framework of optimal control theory and the solution to the mobile robot control problem is based on the concept of ultimate boundedness.

### PUBLICATIONS:

Mukherjee, R., "Design of Holonomic Loops for Repeatability in Redundant Manipulators," Proceedings of 1995 IEEE International Conference on Robotics and Automation, Nagoya, Japan, pp. 2785-2790, 1995.

Mukherjee, R., Emond, B.R., and Junkins, J.L., "Optimal Trajectory Planning for Mobile Robots: A Pendulum Analogy," Proceedings of International Symposium on Intelligent Robotic Systems (ISIRS), Bangalore, India, November 1995.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Modeling and Simulation

**KEYWORDS:** Nonholonomic, mobile robot, space robot, ultimate boundedness, optimal control, repeatability

## OPERATIONAL AND TACTICAL EVALUATION OF SHALLOW WATER NEAR SURFACE SUBMARINE RESPONSE

**Fotis A. Papoulias, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Surface Warfare Center - Carderock Division**

**OBJECTIVE:** The objective of this project was to initiate efforts in characterizing and classifying submarine near surface response in forms that can be directly utilized during preliminary design phases.

**SUMMARY:** Submarine operations at periscope depth become increasingly important as new roles for the Navy in littoral waters are emerging. Particular emphasis so far in this project was placed on computation of steady state forces

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on the body as a function of speed, depth, and wave frequency and direction. Also, several tools for predicting added mass and damping coefficients have been evaluated along with characterization of operational requirements for near surface response in shallow and littoral waters.

## **PUBLICATION:**

Papoulias, F.A. and Papadimitriou H. A., "Nonlinear Studies of Dynamic Stability of Submarines in the Dive Plane," Journal of Ship Research, Vol. 39, No. 4, 1995.

## **THESIS DIRECTED:**

Holmes, E.P., LCDR,USN, "Prediction of Hydrodynamic Coefficients Utilizing Geometric Considerations," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Environmental Quality

**KEYWORDS:** Submarine response, near surface, littoral waters

## **JOINT WARFARE COMBAT SIMULATION MODELS**

**Fotis A. Papoulias, Associate Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Postgraduate School - Institute of Joint Warfare Analysis**

**OBJECTIVE:** The objective of this project was to evaluate various ship maneuvering models and their applicability in real-time visual simulation studies.

**SUMMARY:** A non-linear maneuvering model based on ship geometric and mass properties was developed. This model was used as a benchmark in order to evaluate the accuracy of simpler models. A modified linear model was introduced which is about three times faster than the nonlinear model with very little sacrifice in accuracy, thus rendering it very desirable for applications where on-line implementation speed is important.

## **THESIS DIRECTED:**

LaFontant, P.B., "Development and Assessment of a Ship Maneuvering Simulation Model," Master's Thesis, December 1995.

**DOD KEY TECHNOLOGY AREA:** Other (Design Automation)

**KEYWORDS:** Ship maneuvering

## **TURBULENT VORTEX/FREE-SURFACE INTERACTION**

**Turgut Sarpkaya, Distinguished Professor**

**Department of Mechanical Engineering**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** Understanding of turbulent flow structures resulting from the interaction of swirling flows with a free surface through the use of LDA, LIF, and CFD.

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**SUMMARY:** Detailed analysis and experiments that could eventually serve to elucidate the physics of fluid mechanics phenomena such as the generation of whirls, the quasi-two-dimensionalization of turbulence near the free surface, and the reverse energy cascade at pure and contaminated interfaces constitute the central intent of this on-going investigation. The vorticity flux, surface-tension-related effects, basic equations and boundary conditions, the role of surfactants, topology of interfacial interactions, characteristics of vortex connections, disconnections, and reconnections, a number of canonical flows (single and paired vortices, jets, and swirling jets), and the nonlinear interactions of shear-flow wake turbulence with a free surface are investigated as part of a continuing fundamental research in hydrodynamics.

## PUBLICATIONS:

Sarpkaya, T., "Unsteady Flow—Analysis and Experiments," Chapter 12 in Fluid Dynamics, (Ed. J. A. Schetz), John Wiley & Sons, pp: 12/1–12/45, December 1995.

Sarpkaya, T., "Turbulent Vortex Breakdown," Physics of Fluids, Vol. 7, No. 10, pp. 2301-2303, October 1995.

## OTHER:

Feyedelem, M., "Interaction of a Swirling Jet with a Free Surface," Master's and Mechanical Engineer's Thesis, forthcoming in March 1996.

Sarpkaya, T., "Vorticity, Free Surface, and Surfactants," Annual Review of Fluid Mechanics, Vol. 28, pp. 83-128, to appear 1996.

**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ship and Watercraft

**KEYWORDS:** Non-acoustic detection, submerged bodies, hydrodynamics

## CONDUCTIVITY MEASUREMENTS IN THE WAKE OF SUBMERGED BODIES

Turgut Sarpkaya, Distinguished Professor

Department of Mechanical Engineering

Sponsor: Naval Research Projects Office

**OBJECTIVE:** To obtain a detailed mapping of the spatial and temporal variations of conductivity in the wakes of submarine-shaped bodies.

**SUMMARY:** The variations of the relative conductivity in the wake of self-propelled, single-screw, submarine-shaped bodies in a continuously stratified fluid were measured. The internal Froude-number scaling ( $Fr = U_o/ND$ ) was used between the model and the prototype to select the buoyancy (Brunt-Väisälä) frequency  $N (= [g\Delta\rho/\rho_o H]^{1/2})$  with  $\rho_o$  as the mean density at mid-depth, the model diameter ( $D$ ) and speed ( $U_o$ ) for representative environmental conditions. The model Froude number ranged from about 50 to 200 and the Reynolds number ( $U_o D/\nu$ ), from about  $3 \times 10^4$  to  $6 \times 10^4$ . The boundary layer along the body was tripped to be turbulent. The wake collapse (at a distance of about 400 diameters downstream) gave rise to large conductivity changes and to many modes of short internal waves of mean length  $D$ . The conductivity field ahead of the body anticipated the arrival of the body (the upstream effect or blocking), particularly for the impulsive starts and stops of the body.

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Sarpkaya, T. and Massidda, T. H., "Conductivity Measurements in the Wake of Submerged Bodies in Density-Stratified Media," Naval Hydrodynamics, Vol. 1, pp. 1-12, accepted for publication, presented in Trondheim, Norway.



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Sarpkaya, T. and Massidda, T. H., "Conductivity Measurements in the Wake of Submerged Bodies in Density-Stratified Media," Technical Report to Naval Research Projects Office (Controlled Distribution), March 1995.

## THESIS DIRECTED:

Massidda, T.H., "Conductivity Measurements in Submarine Wakes in Density-Stratified Fluids," Master's and Mechanical Engineer's Thesis, March 1995.

**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ship and Water craft

**KEYWORDS:** Non-acoustic detection, submerged bodies, hydrodynamics

## OSCILLATING TURBULENT FLOW WITH OR WITHOUT A CURRENT ABOUT A CIRCULAR CYLINDER

Turgut Sarpkaya, Distinguished Professor  
Department of Mechanical Engineering  
Sponsor: Naval Postgraduate School

**OBJECTIVE:** A critical assessment of the capabilities of Computational Fluid Dynamics (CFD) in providing time-accurate solutions to massively-unsteady incompressible flows.

**SUMMARY:** The CFD analyses of two sinusoidally-oscillating, turbulent flows, (one with zero mean and one with non-zero mean) at relatively large Reynolds- and Keulegan-Carpenter numbers and relative current velocities, have been performed. The primary purpose of the investigation was a critical assessment of the computational accuracy of time-dependent turbulent flows with large-scale unsteadiness. A number of turbulence models, including the Standard k- $\epsilon$  and Re-Normalization-Group (RNG) based  $\kappa$ - $\epsilon$  model have been used. A second-order in time, second-order in space, second-level predictor-corrector finite difference scheme has been employed. The extensive numerical results compared favorably with those obtained experimentally.

## THESES DIRECTED:

de Angelis, M., "Wave/Current Induced Forces on Circular Cylinders," Master's Thesis, December 1995.

Hanson, C.D., "Numerical Analysis of Oscillating Flow about a Circular Cylinder," Master's Thesis, December 1995.

## OTHER:

Sarpkaya, T., de Angelis, M., and Hanson, C., "Oscillating Turbulent Flow With or Without a Current about a Circular Cylinder," accepted for publication in Journal of Offshore Mechanics and Arctic Engineering, ASME Paper No: OMAE-38.

**DOD KEY TECHNOLOGY AREA:** Surface/Under Surface Vehicles - Ship and Watercraft

**KEYWORDS:** CFD, submerged bodies, unsteady flows, hydrodynamics

# MECHANICAL ENGINEERING

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## NUMERICAL STUDY OF UNDEX PROBLEMS: WATER-BACKED COMPOSITES, SURFACE COATINGS, AND GAS BUBBLE-STRUCTURE INTERACTION

Young S. Shin, Professor

Young W. Kwon, Associate Professor

Department of Mechanical Engineering

Sponsor: Defense Nuclear Agency

**OBJECTIVE:** To advance our understanding on (i) dynamic response and failure of water backed composite structures subjected to an underwater explosion, (ii) effects of surface coating on dynamic behavior of structures exposed to a shock loading, and (iii) numerical simulation and modeling of gas bubble, structures and their interaction using Lagrangian-Eulerian finite element analysis approach.

**SUMMARY:** The numerical simulation of explosion gas bubble motion in the fluid has been investigated. The rigid, the free surface (constant pressure) and non-reflecting fluid boundary conditions were considered. The boundary curvature effect on gas bubble oscillation was studied. The gas bubble motion near the simple flexible boundary was also studied. The numerical results were compared with the experimental results if available. The results of the Lagrangian-Eulerian finite element analysis are quite promising. The numerical modeling includes 1- and 2-dimensional problems.

### PUBLICATIONS:

Chisum, J. E. and Shin, Y. S., "Coupled Lagrangian-Eulerian and Multimaterial Eulerian Analysis in Underwater Shock Research," Structures Under Extreme Loading Conditions, ASME 1995 PVP-Vol. 299, pp. 33-38, July 1995.

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### THESIS DIRECTED:

Kaufman, R. E., LT, USN, "Effects of Geometric and Material Imperfections on the Dynamic Response of Cylindrical shells Subjected to Underwater Explosion," Engineer's Degree in Mechanical Engineering, June 1995.

### OTHER:

Shin, Y.S. and Hooker, D.T., "Damage Response of Submerged Imperfect Cylindrical Structures to Underwater Explosion," accepted for publication and to appear in Journal of Computers and Structures.

**DOD KEY TECHNOLOGY AREA:** Environmental Quality

**KEYWORDS:** Underwater explosion, explosion gas bubble, Lagrangian-Eulerian Analysis

# **MECHANICAL ENGINEERING**

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## **SHOCK AND VIBRATION RESEARCH IN SUPPORT OF ADVANCED LIGHTWEIGHT INFLUENCE SWEEP SYSTEM (ALISS)**

**Young S. Shin, Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Surface Warfare Center - Carderock Division**

**OBJECTIVE:** The scientific objectives include (i) to study the operational environment in which the ALISS must be designed to perform and to make a recommendation on shock and vibration design criteria, (ii) to conduct a review of the magnet shock test apparatus currently in use and to make any design modification if any, and, (iii) to review the common cryogenic supports which are candidates for use in the ALISS and to design a shock test apparatus to test the performance of these cryogenic supports.

**SUMMARY:** This is a on-going shock and vibration research project in support of Advanced Lightweight Influence Sweep System (ALISS). ALISS is an Advanced Technology Demonstration to validate the feasibility of superconducting technology to sweep magnetic influence mines. A Superconducting Mine Countermeasures (SCMCM) system would be small, light, and simple compared to currently deployed MCM system. When ALISS is constructed as a superconducting mine countermeasure, the system must perform satisfactorily under the extremes of shock and vibration environment encountered in military applications. The tasks conducted include: (i) normal mode and transient response analysis of 1/4-scale superconductor magnet SCMCM model (GE and GA concepts) and, (ii) to develop the shock and vibration criteria for ALISS.

### **THESIS DIRECTED:**

Wagnon, D.L., LT, USN, "Dynamic Design Analysis of a Shipboard Antenna Structure Subjected to Underwater Explosions," Engineer's Degree in Mechanical Engineering, June 1995.

**DOD KEY TECHNOLOGY AREA:** Materials, Processes and Structures

**KEYWORDS:** ALISS, superconducting mine countermeasures, Light Weight Influence Mine Sweep System, shock and vibration

**1995**

**Faculty Publications  
and  
Presentations**

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